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A SEARCH: NEW TECHNOLOGY FOR PAVEMENT
SNOW AND ICE CONTROL

Abt Associates, Incorporated

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**A Search:
New Technology for
Pavement Snow and Ice Control**



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Donald M. Murray
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Results of the study indicate that: (1) More information is needed on salt damage to the environment, highway structures, and vehicles in order to perform accurate cost-benefit analyses of alternative approaches. (2) More complete knowledge is needed on the effects of alternate chemical deicers. (3) Pavement heating is an expensive means of removing snow and ice but can be justified in special cases for safety or environmental reasons. (4) Two mechanical devices, snow plow with compressed air and a brush and blower system require further testing and development. (5) Research is required to identify a hydrophobic substance which can be applied to pavement to reduce ice adhesion.

A brief cost estimate of the various approaches has been included. (EPA)

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A SEARCH: NEW TECHNOLOGY
FOR
PAVEMENT SNOW AND ICE CONTROL

by

Donald M. Murray

Maria R. Eigerman

Contract No. 68-01-0706

Project No. Z-800615

Project Officers:

Richard Field

Hugh E. Masters

Storm and Combined Sewer Technology Branch
Edison Water Quality Research Laboratory, NERC
Edison, New Jersey 08817

Prepared for:

OFFICE OF RESEARCH AND MONITORING
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

ib

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ABSTRACT

A study was undertaken to search for new approaches to the problem of snow removal and ice control in vehicular and pedestrian usage areas. Proven techniques of technology transfer were applied for the purpose of identifying technologies that have not yet been utilized for deicing purposes. Contacts with specialists and a "brainstorming session" were used to determine strategies for searches of computerized data banks. Although several approaches were identified, none are immediately usable.

Results of the study indicate that: (1) more information is needed on salt damage to the environment, paved areas, highway structures, and vehicles in order to perform accurate cost-benefit analyses of alternative approaches. (2) More complete knowledge is needed on the effects of alternate chemical deicers. (3) Pavement heating is an expensive means of removing snow and ice but can be justified in special cases for safety or environmental reasons. (4) Two mechanical devices, snow plow with compressed air and a brush and blower system require further testing and development. (5) Research is required to identify a hydrophobic substance which can be applied to pavement to reduce ice adhesion.

A brief cost estimate of the various approaches has been included.

This report was submitted in fulfillment of Contract No. 68-01-0760 under the sponsorship of the Environmental Protection Agency.

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SECTION I

CONCLUSIONS

The genesis of this report was a mounting concern that the continued broadcasting of deicing chlorides onto streets, highways, and other pavements would have irreversibly harmful effects on the environment. The litany of arguments against chemical solutions to snow and ice control was familiar:

- Pavement salting causes saline intrusions into ground and surface waters, contaminating them as habitats for sensitive fresh-water organisms critical in the food chain.
- Brines running off pavements and thrown into the air by passing vehicles contribute significantly to the scorching and die-off of roadside vegetation.
- Increasing levels of salt in public water supplies pose a threat to the public's health. Individuals restricted to low-sodium diets may suffer adverse physical effects or be required to seek alternate sources of supply. In addition, increased hardness may make existing supplies unfit for industrial and commercial purposes.
- Increased amounts of salt runoff collected by sewers cannot be handled by existing treatment plants; the cost for the required equipment is very high compared to present facilities.
- Vehicle corrosion is greatly speeded by continual exposure to salt, in some cases to the extent of structural damage hazardous to the motorist.
- Corrosion of bridge decks and other highway structures caused by salt creates an expensive and sometimes dangerous situation.

From all these factors issued the first premise of our study: the

continued application of vast tonnages of conventional deicing chemicals and their additives to the pavements of snowbelt states is inimical to their respective ecosystems and inconsistent with rational policies of environmental management. This position is not a wholesale rejection of chemical deicers. Judicious salting in selected areas tolerant of salt is acceptable.

Our hypothesis is that a search for new techniques constrained to perform within the bounds of reduced total cost to the public would reveal innovative technology for snow and ice removal.

By applying a proven method for accessing technology responsive to a well-defined problem, we explored

- 1) research and development beyond the state of the deicing art
- 2) techniques generated for other applications but unutilized for deicing

Despite our confidence that this approach would be productive, however, it must be emphasized that we neither sought nor expected to find "the answer" to the bare pavement vs. environmental integrity dilemma. Indeed, there can be no universal solution for what is a highly individual problem. Blocks of geography have characteristics peculiar to each of them, making prescriptive findings or "best" practice of uncertain value. A single technological find, while useful in one dimension of the deicing problem-say, thermal efficiency-may be infeasible in some contexts because of another factor, e.g., extraordinary energy requirements.

Searches for new technology have proved to be effective means of problem solving. However, the method does not guarantee that a solution exists. In the case of our search for alternate approaches to the snow and ice problem, technology transfer has been relatively unsuccessful. The project has found two methods of snow removal which are useable but require development, and two conceptual approaches which require further research. If one of the two concepts eventually proves

to be useful, then the method will have demonstrated its value. If this is not the case, then the study will have at least enumerated the existing techniques, demonstrated the nature of the required solution, and shown that no obvious approaches have been overlooked.

SECTION II

RECOMMENDATIONS

There have been three major approaches identified by this report: continue to use salt but find a method for negating its effects, develop improved mechanical means of removing snow and ice, or prevent ice from forming or adhering to the pavement. The chief recommendations stemming from these approaches are:

- 1) Much more knowledge of salt damage to the environment, pavement, highway structures and vehicles is a necessity. A method for assigning costs to the damages must be devised. Without this information it is difficult or impossible to accurately assess the benefits of alternate approaches or justify their implementation.
- 2) More complete knowledge of the effects of certain alternative chemicals, including their potential effects on the environment (i.e. biodegradability, toxicity, etc.), is required. These are: Ethylene glycol, formamide, urea, calcium formate, ammonium acetate, Union Carbide's UCAR Deicing Agent, and proprietary products sold by Kaiser and Monsanto. It is conceivable that one or a combination of these chemicals would have a lower total cost to the public than salt.
- 3) Pavement heating is an expensive means of removing snow and ice but can be justified for special locations such as bridge decks, hazardous intersections, or near water supplies that cannot tolerate salt. This approach is almost immediately available for implementation.
- 4) Pursue testing and development of two mechanical devices: Compressed air with snow plow and brush and blower system.
- 5) Pursue search for a hydrophobic substance which can be used to reduce the adhesion of ice on pavements. While this approach is the most remote at the present time, it is potentially the most valuable.

SECTION III

INTRODUCTION

Technology Transfer

This section describes the methods of technology transfer and the specific steps taken for the snow and ice problem. Our experience with technology transfer has involved: (1) the development of effective and efficient methods for transferring technology from one context to another and (2) the application of aerospace technologies to urban problems. The process by which these objectives are achieved has three major phases: problem identification, technology identification and technology transfer implementation. The activities internal to each of these phases are discussed below. It should be pointed out, however, that the progression of activities for any one transfer effort is not necessarily sequential, moving from problem identification to technology searching to technology implementation. Sometimes these activities proceed simultaneously, sometimes iteratively. For example, initial work toward implementation of an identified problem-technology match may require redefining the problem and subsequently considering alternative technologies.

Problem Identification

Technology transfer occurs at a rather specific level of detail. It therefore requires that the problem be well-defined. The purpose of a detailed definition is to provide sufficient description and analysis of the problem such that the chances of identifying relevant technology will be maximized. For the current project on snow and ice removal, a literature review was undertaken to determine various aspects of the problem, including present-day methods. This review, and contacts with several engineers (see Appendix B) provided the basis for generating new approaches. While we found that there was ample literature on both the physical properties of snow and ice and on snow removal methods, there was a severe lack of knowledge regarding salt damage and the safety aspects of salt use. A major result of our problem identification task was the development

of an approach to deicing as shown in Figure 1. The first decision box in the flow chart represents the question, "Should we allow ice and snow to remain on the pavements with the resultant need for improved tire and vehicle design, or should we continue to remove it?" The second decision point represents the question, "Given that we must remove ice, should we use deicing chemicals or find another approach?" The third decision box indicates the question, "Given that we will not use chemical deicers, but must not allow the ice to remain, shall we remove the ice after it forms or not allow it to form in the first place?". This flowchart formed the basis for our search for new technologies.

Technology Identification

This phase of technology transfer involves the generation of many types of alternative solutions. Besides general contacts with people knowledgeable of the problem, one of the key components is a "brainstorming" session. The session is held with engineers and scientists in an attempt to generate many solution approaches. The "brainstorming" technique has proved to be very valuable in past technology application work and has become an accepted step in the process of reaching technological solutions. For this project, a session was held with five senior scientists and engineers from the Massachusetts Institute of Technology faculty: Professor Clark Colton, Chemical Engineer; Professor Fred Moavenzadeh, Civil Engineer specializing in highway problems; Professor Lynn Gelhar, Hydrologist; Professor David Adler, Electrical Engineer; and Professor David Wilson, Mechanical Engineer.

The insights gained from this session were used to develop specific search strategies for accessing computerized data banks. These strategies are formulated by alternative combinations of key word descriptors. For the snow and ice search, three data banks were accessed - Chemical Abstract Condensates, the National Aeronautic

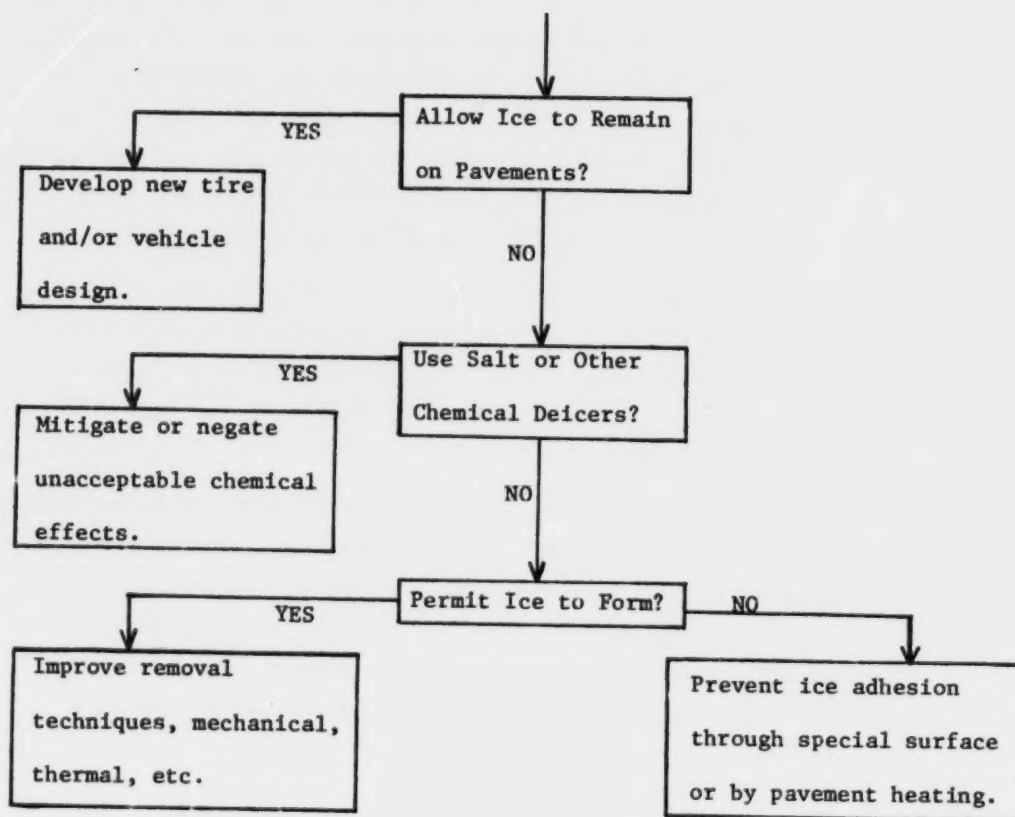


FIGURE 1
Approach to Deicing

and Space Administration files and the Bibliography on Cold Regions Science and Technology. In addition, manual searches were performed on Highway Research Abstracts, Engineering Index, U.S. Government Research and Development Reports, British Technology Index, Government Printing Office Monthly Catalog, Applied Science and Technology Index, and Highway Research Information Service Abstracts. Sample pages from the computerized searches are presented in Appendix A.

Upon receipt of the computer printouts, titles of documents were reviewed for their relevance. Abstracts of these documents were read and screened a second time. The documents which survived this second process were then ordered in microfiche or hard copy form for detailed review.

Computerized searching identifies not only technologies themselves, but technologists who are involved in continuing research efforts. It is especially important to discuss a problem directly with the engineer because documentation can be outdated and significant advances with a technology may not yet have been recorded. Further, he may be aware of related projects in progress elsewhere which bear more directly on the problem.

Technology Implementation

Once a potentially useful technology is found, it is carefully evaluated for its technical feasibility. If it appears sound from the technical point of view, before expending any resources on applications engineering, it is investigated for its economic feasibility. This requires an analysis of the characteristics of commercially available products now attempting to meet the same need. The competitive advantage of the technology over commercial technologies should be estimated on either a cost or quality basis.

Additional phases of technology implementation include feasibility testing, performance testing, prototype development, and determination of production and marketing costs. These subsequent steps, however, proceed beyond the scope of our project on snow and ice control.

SECTION IV

STATE OF THE ART REVIEW

An extensive review of the literature and current research on snow and ice control was undertaken in order to place the study findings in a proper perspective. It is not necessary here to provide an exhaustive account of our search since previous studies have described the range of available equipment and techniques. This section is intended rather to summarize our overall findings and focus attention on recent work which has not yet received detailed coverage in the literature.

Essentially all pavement snow and ice control in the United States is performed by the long-established methods of plowing, sanding and salting. While there are numerous types of plows, snowblowers, and abrasives, and techniques for their use, the basic approach has remained the same. This is not surprising considering there has been no continuing program to provide for systematic research on new equipment, materials and techniques. Government funding has been scattered and insufficient; industry is not capable of supporting the type of research required to significantly advance the state of the art. Thus, what research projects have been undertaken on either the public or private level have not yet produced innovative techniques which are economically feasible.

A significant portion of the recent work, both state of the art reviews and new research, has been performed at U.S. Army Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire. This facility sponsors the Bibliography on Cold Region Science and Technology (1), and has published several other documents on pavement snow and ice control (3,4). The laboratory also maintains an extensive library of material on the subject. Some of their recent research will be discussed later on in this section.

The Highway Research Board has also published a number of reports related to pavement snow and ice control (2,5,6,14,16, 36,37,39,54). These reports help to disseminate information

on the latest devices and techniques. Finally, there are a number of trade journals (8) which carry a variety of articles on new equipment and maintenance methods. These journals discuss materials and equipment which are commercially available for use. Such publications reach many of the persons who are actually responsible for winter maintenance efforts.

Beyond the standard methods of plowing, salting and sanding, many other approaches have been tried. The first of these are mechanical means aside from simple plowing. Table I lists the basic types of mechanical devices which are used regularly. Categories 1 and 2 in the table are conventional devices which are used regularly. Categories 3 through 6 have all been tried, but are not used in an extensive or systematic way. Blowers have been employed to clear the pavement surface of loose and, especially, low density snow. However, their use is limited to snow of this type and they are not capable of directing or piling the snow as it often must be. Power brooms consisting of engine driven rotary brushes have been tested for use on airport runways (3). The brooms have proven to be most useful with wet snow and slush. They have not been employed on the highway to date.

Ice crushing rollers have undergone limited testing (3). While they can be used effectively, proper operation is critical to avoid pavement damage. Ice melting machines consisting of forced draft oil burners have also been tested at airports. The burners must be moved over the pavement very slowly. Such burners do not do a thorough job of deicing and furthermore can cause noticeable softening of the pavement.

The combinations of equipment listed last in Table I are, of course, more effective than are the individual pieces of machinery. The blade and impeller, or blade and cutter combinations have been used successfully but are not widely available. The broom and blower combinations have been tested only in prototype form.

TABLE I

MECHANICAL DEVICES FOR SNOW REMOVAL AND ICE CONTROL

1. Blade or Displacement Plows
 - 1.1 Front Mounted
 - One-way Blade
 - Fixed Position (right or left cast)
 - Reversible (swivel or roll-over)
 - V-Blade
 - 1.2 Underbody
 - Road Grader
 - Truck Mounted
 - 1.3 Side Mounted (wings)
 - 1.4 Trailing
2. Rotary Snow Blowers
 - 2.1 Two-element (impeller)
 - Auger
 - Horizontal Axis
 - Vertical Axis
 - Swept-back Axis
 - Cutters
 - Helical
 - Horizontal Breakers (rakes)
 - 2.2 Single-element (no impeller)
 - Scoop Wheel
 - Drum
3. Pure Blowers
 - 3.1 Compressed Air Jet (compressor fed)
 - 3.2 Combustion Jet (jet engine)
4. Power Brooms (rotary brush)
5. Specialized Ice Removing Equipment
 - 5.1 Ice Crushing Rollers (pressure cutting edges)
 - Wobble Wheel
 - Spiral Rolls
 - Serrated Blade
 - 5.2 Ice Melting Machines
6. Combination Equipment
 - 6.1 Blade and Impeller
 - 6.2 Blade and Cutter
 - 6.3 Blade and Compressed Air
 - 6.4 Broom and Blower
 - 6.5 Burner and Blower
 - 6.6 Burner, Broom and Vacuum

They appear promising for use in removing low to medium volume snow which is not very hardpacked. As with the blower alone, the broom and blower combinations often cannot cast the snow far enough or cast it in the correct direction. There is still a need for improvement of such equipment.

One combination which appears to hold promise for the future is the use of compressed air in conjunction with a snowplow blade (13). Air is forced out of the edge of the plow blade and is directed onto the pavement along the plow's angle to the road. The plow blade does not make contact with the pavement (thus saving wear on plow blades and pavement surfaces), as the compressed air lifts the snow off the road onto the blade. The method works no better than a conventional blade on ice but is very effective for removing light to heavy snow. To date, only small shovel-sized models have been tested; a satisfactory compressor has not yet been found for use on a full size plow.

Chemical Treatment

Chemicals are commonly used on ice pavements to melt and break up the ice. They can also be used in advance of a snow storm to prevent ice adhesion and snow build-up. Chemical action is a result of the freezing point depression that occurs in the water, ice and chemical mixture. Since the degree of depression depends upon the number of molecules or ions of the chemical in the mixture, the most effective chemicals are those which ionize in solution and have low molecular weight. There are a number of soluble salts and other substances which are capable of substantially depressing the freezing point. However the choice of chemical is limited by cost, ease of handling, and degree of damage caused to the pavement vehicles and the environment. The chief advantage of salt is that it is both very low in cost and quite effective.

Some of the other chemicals which have been proved effective are: urea, formamide, urea-formamide mixture, ethylene glycol, ammonium acetate, tetrapotassium pyrophosphate (KPP), and several proprietary products. While all of these chemicals eventually biodegrade, the manner in which this occurs combined with the climatic conditions determine the effects on the environment. For example, during the

winter months only a small amount of biodegradation of the accumulating chemical might occur and, if the chemical were not carried away by surface or ground water, there would be a high concentration of the chemical during the spring melt. Such high concentration could cause serious vegetation damage and abnormal algae growth in surface waters. Thus the environmental hazards of these chemicals are very dependent on local conditions. At any rate, these chemicals are very expensive, the cheapest being almost ten times the cost of salt. At present, only airports are able to justify this cost through the reduced occurrence of corrosion. Further tests must be performed on all of the alternate chemicals to determine exactly their dangers to the environment and their effects on roads and other paved areas, bridge structures, and vehicles.

Pavement Heating

There have been a number of experiments with heated pavements over the past several years (17,18,19,20,21,22,22). Such an approach allows for the melting of snow and ice before any appreciable amount can form. Some systems have been designed to operate automatically, sensing the presence of ice or snow and thus removing the need for observation by an operator. The pavement heater must supply sufficient heat to melt the ice or snow while simultaneously undergoing the unavoidable heat losses both to the ground and to the air. The heat output required is determined largely by the weather conditions - air temperature, windspeed, humidity and snowfall rate, but is also dependent on ground temperature and previously accumulated snow or ice. There are two types of heaters: fluid circulating systems and electrical resistance mats.

Fluid circulating systems usually consist of pipes carrying a low freezing point liquid, heated by an oil-fired furnace or other device. The pipes are placed a few inches below the surface of the pavement at the time the pavement is laid. The temperature and circulation rate in the pipes are such that the pavement is maintained

at 1 or 2° F above the freezing point. The pipes are usually closely spaced (about 1 to 1 1/2 feet apart) and set in concrete. There are also circulating systems having no heating element, which instead use the earth as a heat exchanger (17,18,20,21). This system utilizes the heat stored in the earth to warm the pavement. One set of pipes is laid a few inches from the pavement surface as they are with the regular heating systems, but another set of pipes is laid 10 - 15 feet below the surface. The two sets are connected and the fluid in the pipes is circulated by a pump. (See Figure 2) Although the initial cost of excavation for this system is higher than with heated systems since pipes must be laid so far below the ground surface, the operating cost is negligible.

Electrical pavement heaters are of three types: high voltage insulated cable systems, low voltage systems using uninsulated metal mesh, and electrically conductive pavements (4,23,61). (See Figure 3) These systems work quite well and are less expensive to install than the fluid circulating systems, although the operating costs are somewhat higher. Recent experiments (61) with the electrically conductive pavements have found an encouraging ease of repair and replacement. Operating costs are very similar to that of the cable or mesh systems. Electrical pavement heating is most common in England where a number of sections of road are being tested. Total annual operating costs are on the order of fifteen to thirty times that of salt.

Ice Adhesion and Release

One alternate approach is to find ways of reducing the adhesion of the ice (25,26,27,28,29,30,31,32,33). Most research has been directed toward solving the ice adhesion problem on equipment and not on pavements. Although the work may be extended to include pavements, most substances used have low friction characteristics and could not be used. This approach has not been fully investigated and is the subject of further discussion in later sections of this report.

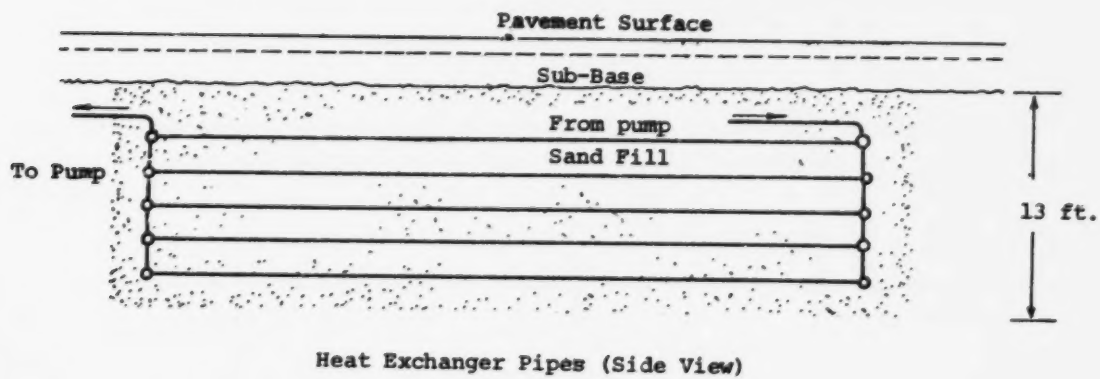
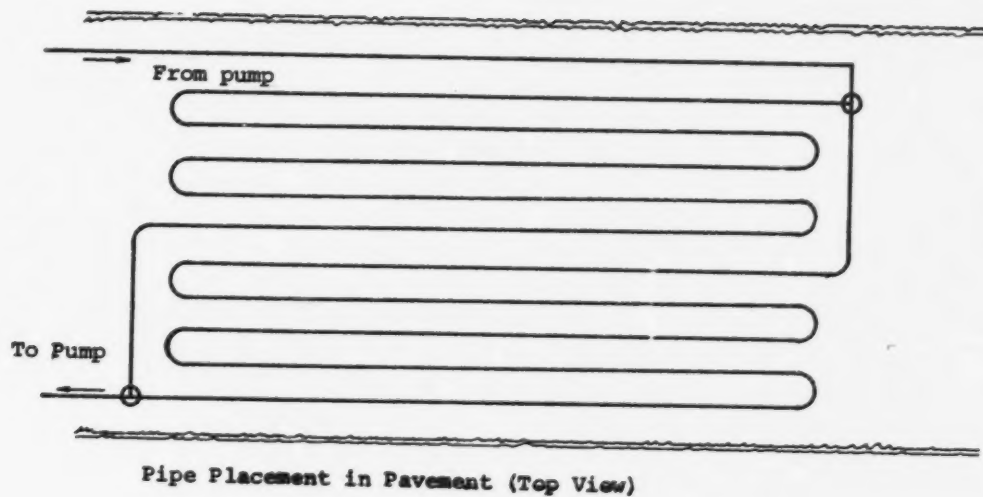


FIGURE 2

Fluid Circulating Heat Exchanger

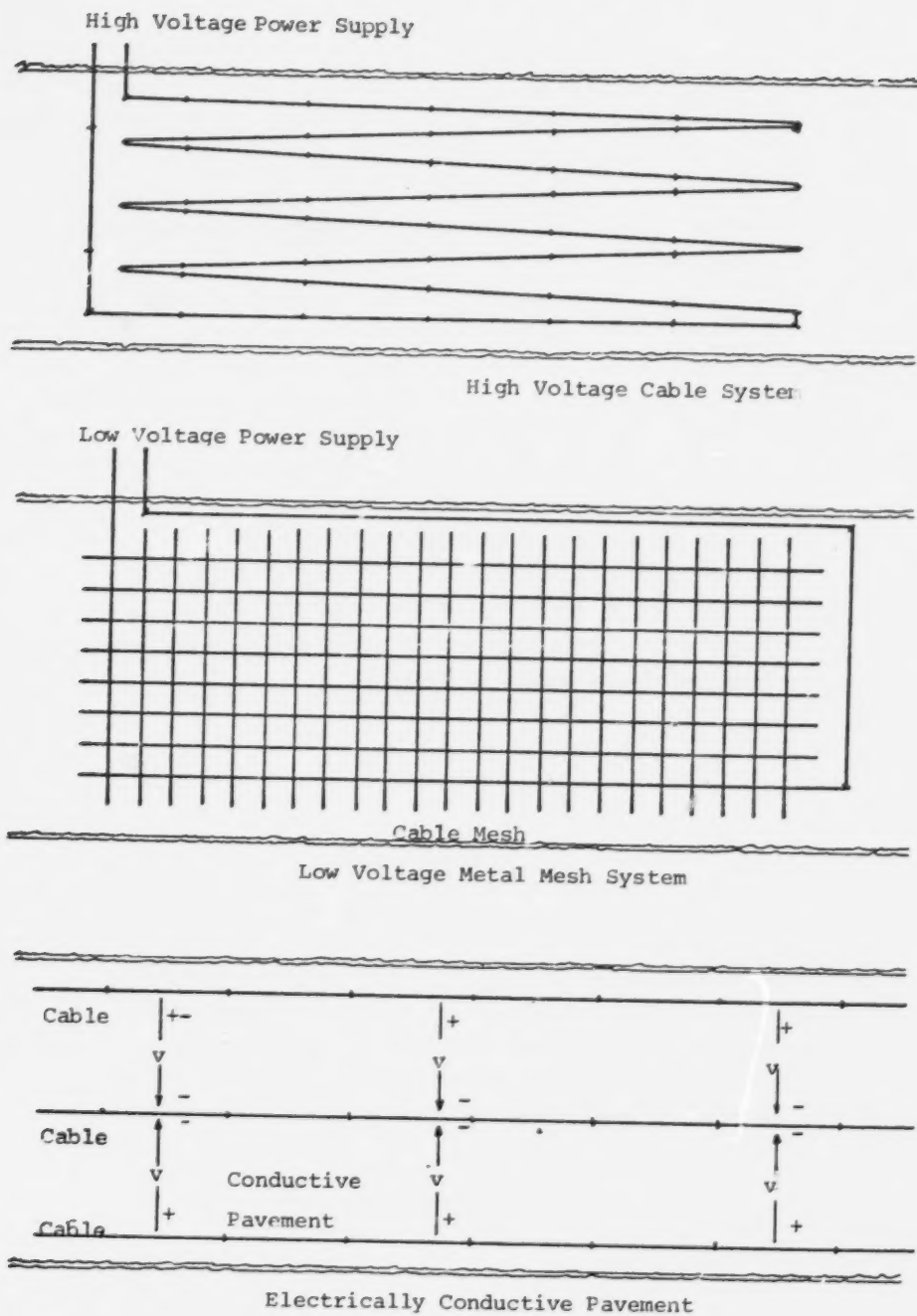


FIGURE 3
Electrical Pavement Heaters (overhead view)

Other Approaches

Attempts have been made at using dyes or coal dust sprinkled on the snow to increase the absorption of solar radiation and thus raise the rate of melting. Although melting does increase slightly, the amount cannot justify the application and cleanup costs.

Ultrasonics or vibrational energy techniques have been used to break up ice on the pavement. While the method should work well in theory, in practice the energy losses are so great as to make the process highly inefficient.

Similarly, the use of electromagnetic energy to break up ice has also proved very inefficient. One test (24) involved the use of xenon flash lamps to vaporize the ice at the surface of the pavement causing the surface ice to explode away. While this approach is certainly a satisfying one, there is little hope that it could ever be put to practical use because the energy requirements are too great.

SECTION V

DISCUSSION OF FINDINGS

The literature review and technology reconnaissance generated a large number of approaches to snow and ice control. Most of these were found in the literature, and have already been tried in varying degrees. Some of these were failures; others were not practical solutions in the sense that they are not both technically and economically feasible. For example, the technique of shattering ice with electromagnetic energy is technically impracticable because a vehicle could not carry a large enough power generating and capacitative discharge system; and the idea of using pavement heating in all locations is economically unjustifiable. The approaches described in this section are restricted to those which are either presently or potentially viable from both an economic and technical standpoint. The discussion will follow the "Approach to Deicing" outline in Figure 1.

New Tire and/or Vehicle Design

One obvious direction for research and development is the redesign of components of the road vehicle itself, such as tire tread or tire structure, tire accessories, braking systems, suspension systems, etc. Substantial efforts, chiefly on the part of automobile and tire manufacturers, have already been made in this area and will continue. We elected not to pursue this in part because it is already the subject of active research, but principally because the problem it poses - that of vehicle design - has wholly different dimensions from the central concern of the present study - that of clearing road surfaces. Moreover, it is our belief that vehicle design alone will not, in the short or medium term, obviate the necessity to free roads from snow and ice.

Negation of Chemical Effects

A second approach is to allow the continued use of salt or other chemicals and to somehow alter their effect on the environment. We would first point out that further testing is required to determine

the dangers of the alternate chemicals such as ethylene glycol, formamide, urea, etc. While they are totally biodegradable and could conceivably be safe under the proper conditions, their total effects are not well known. It is clear that under some circumstances, particularly when the chemical level rises in a locality, each of these can have definitely harmful effects on the environment. Consequently, we suggest that these chemicals be studied more thoroughly before attempting to find a method of negating effects which are not yet well understood.

If the use of salt is to continue at the present level, it appears that its effects must somehow be counteracted or eliminated. Collection of the salts after they have served their purpose on pavements would require special drainage and collection systems which appear wholly impracticable (not true for salt storage piles, of course). Another tack is to chemically alter the action of the salt. In theory this could be accomplished by applying a chelating agent to the highways after the salt was no longer needed. A satisfactory agent would, immediately upon contact, tie up most of the sodium ions, making them unavailable for chemical reactions. A chemical equilibrium would be maintained between the free sodium and the combined sodium and, given a sufficient amount of the chelate, the free sodium could be kept at an acceptable level. However, as the free sodium ions left the solution via ground or surface waters, more sodium ions would be released by the chelates. Eventually all the sodium would be released into the environment (not all in the original location) although the concentration would be maintained at a reasonable level. It is questionable whether such an approach would be effective, or if it would only introduce a time delay in the effect of the salt. In addition, it would have to be shown that the chelating agent itself was not harmful to the environment. To date, a satisfactory chelate has not been identified.

Improved Removal Techniques

If we must keep our paved areas clear of ice and snow, and simultaneously restrict our use of chemicals, it is essential that we devise removal techniques that are more effective than the present

inadequate methods of plowing and sanding. It is difficult to predict whether or not a purely mechanical means will ever be developed capable of completely removing glare ice from the pavement. During the course of this study we have not been able to pinpoint a feasible solution, and we doubt that one exists. The adhesive bond that ice forms with the pavement is often stronger than the cohesive forces of the pavement itself. Consequently, if one tries to mechanically break the interfacial bond, the pavement breaks apart first. The potholes and cracked pavements seen during the winter months are often the results of a plow being used to "scrape off the ice".

The problem of adhesion does not exist with snow, however, and there is hope for improving its removal. Dr. C. J. Posey of the University of Connecticut has worked with the Connecticut Department of Transportation to develop a snow plow blade which works in conjunction with compressed air to clear the pavement. (13, 62) This device utilizes a conventional plow blade with an attached air pipe that directs a thin sheet of high velocity air onto the pavement at the angle of attack of the blade. (See Figure 4) This stream of air loosens and lifts the snow so that the plow blade can move it off the road. The advantages of this system are that:

- 1) snow in cracks and uneven portions of the pavement can easily be removed, and
- 2) the plow does not have to be in contact with the pavement, saving wear on both the road and the blade.

It is thought that with high enough pressure, even dense snow could be lifted from the pavement. Experiments have been successfully performed with a shovel-sized test apparatus. Wet snows up to four inches deep (not tested in deeper snow) were easily cleared from the pavement. A full size plow was then equipped with a similar setup and tested on highways. Unfortunately the compressor did not supply a high enough volume of air and the project has been temporarily suspended until an adequate compressor can be found.

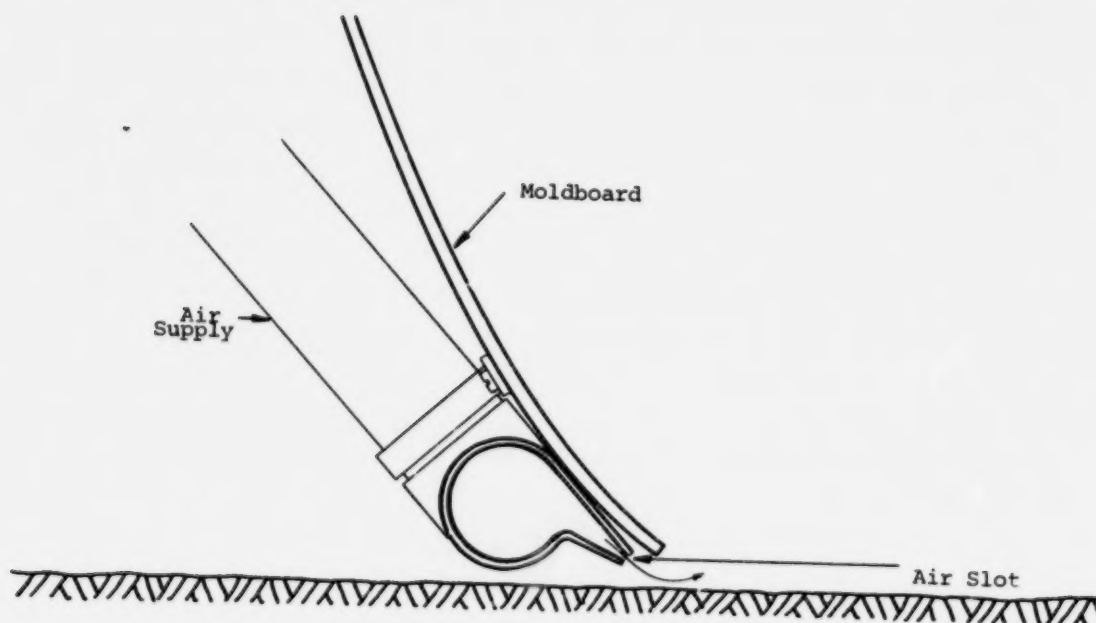


FIGURE 4
Compressed Air Jet and Snow
Plow Blade

One other mechanical approach which merits further development and testing is a broom and blower system (See Figure 5). The broom consists of a rotating drum that contains rows of steel bristles. The broom can be positioned at different angles to change the direction in which the snow is brushed. The blower follows the broom, clearing all the loose snow and ice particles left on the surface. The device works best with heavy snow or slush. Light snow is just blown around and left behind; hard packed snow is not completely removed. The brush and blower might be most effectively used in combination with a snow plow - plow on the front, brush under the truck, and blower at the rear.

Prevention of Ice Adhesion By Pavement Heating

One obvious way to prevent ice adhesion is to prevent ice from forming at all through the use of heated pavements. Pavement heating has been tried extensively for nearly 20 years. There are two major methods of heating. The first type consists of a fluid circulating system which can either use a fuel burning heat source (such as an oil burner) or use the earth as a heat source. The latter has lower operating costs because there are no fuel supplies or machinery to monitor; however, the initial capital costs are high because of the requirement for placing a set of pipes 12 to 15 feet deep under the pavement. The second type of system utilizes electric power to heat the pavement either by embedded current carrying cables or by electrically conductive pavement. The first of these has been more fully tested since the second is fairly new. However, conductive pavements could be less expensive for initial installation and for maintenance. Power requirements are about the same.

Pavement heating is a fairly expensive approach and extensive use could not be justified. However, it could prove quite valuable and cost effective in special cases - on bridge decks where chemical damage cannot be tolerated, at dangerous highway locations where snow and ice cannot be allowed to remain, or in limited areas where the environment cannot withstand chemical use.

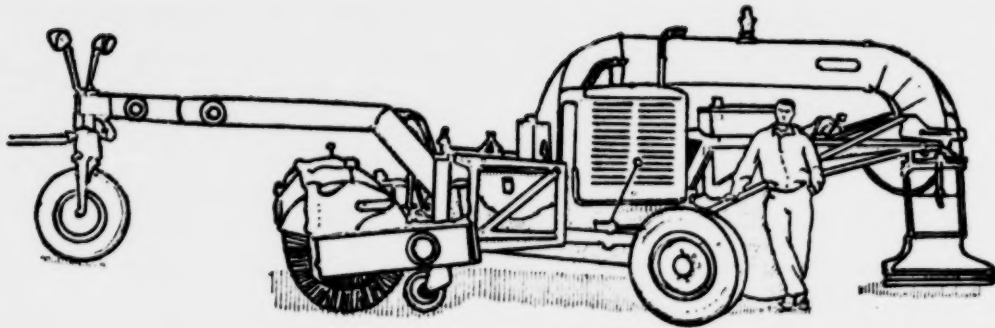


FIGURE 5
Broom and Blower System

Prevention of Ice Adhesion By Hydrophobic Surface

The other approach to prevention of ice adhesion is the use of special road surfacing substances. Many studies have been made on ice adhesion in general and a few experiments have been performed on ice releasing agents for aircraft exteriors and outdoor mechanical equipment. However, little has been done to directly investigate the use of such agents on pavement. The addition of a hydrophobic or icephobic (water or ice repellant) substance to a pavement surface would theoretically produce a significant reduction in the adhesive forces of any ice that might form. Possibly the movement of an automobile tire over the surface would cause the ice to crack or break away, exposing the bare pavement. The pieces of ice could then be removed by a snow plow. The substances which have been developed for other applications are not appropriate for highway pavement because they have low friction characteristics and would last only briefly on pavement surfaces.

We believe that this approach, reduction of ice adhesion by use of a hydrophobic substance poses the greatest opportunity for significantly advancing the art of ice and snow removal. The substance required must be capable of being applied to existing roads, be long lasting, have negligible effects on friction, and be reasonably priced.

While a specific substance which can fill all of these requirements has not yet been identified, there are a number of existing compounds which should be tested before new research is begun. These compounds are all characterized by their ability to form a fairly strong bond to a surface while leaving no available bonds for water molecules, thus "repelling" any water that comes in contact with it. There are three major classes of compounds; Cationic Surface Active Agents, Organo-Fluorochemical Compounds, and Organo Silicone Compounds. Fatty-quaternary-ammonium compounds, a subgroup of the first class listed above, might be particularly suitable. Such a compound, when dissolved in the proper solvent(s), could be sprayed on the road surface pro-

ducing the desired film. This film would adhere to the road because the positively charged cationic agent would be attracted to the negatively charged road surface. Although such a film would repel water its wearlife can not be predicted easily without testing. A few specific examples of such a substance are:

"Aliquat H-226", Dimethyl-tallow-ammonium chloride made by General Mills Chemicals Inc.

"Arosurf TA-100", Dimethyl-tallow-ammonium chloride and "Cationic Softener-x", Alkyl-imidazoline-derivative both made by Onyx Chemical Co.

"Ceramene H.C.", Fatty amide derivative made by Sandoz Colors and Chemicals

"Hipochem Aquaprufl", Quaternary methylol amide made by High Point Chemical Corp.

"Scotchgard", a soil repellent chemical made by Minnesota Mining and Manufacturing Company, is an example of an Organo-Fluorochemical compound. While this specific chemical may not be applicable to the ice release problem, this class of compounds deserves consideration.

Finally the Organo Silicone Compounds, for example, siloxane resins, should be evaluated. Two companies involved in the area of silicone chemistry are Dow Corning and General Electric Silicone Products Department.

It is the professional opinion of Dr. Anthony E. Lintner, a chemical engineer and specialist in surfactants, that it should be possible to develop a substance that would reduce the adhesion of ice on pavements. We therefore recommend that research be undertaken in this direction.

SECTION VI

EVALUATION OF FINDINGS

In order to determine the potential benefits of alternative snow and ice removal approaches, it is necessary to compare each to the present method of salting. Such an analysis must be comprehensive, covering all of the costs involved both tangible and intangible. Cost estimates for the use of sodium chloride and calcium chloride cannot be based on acquisition and spreading costs alone. Costs incurred from damage to automobiles, highway structures, and the environment must also be evaluated. Unfortunately, there is a severe lack of knowledge of these costs - especially the cost to the environment. While there have been a few studies reporting specific instances of damage to roadside wells (35,36, 40,43,46), ponds (35,40), and vegetation (35,36,39,40,41), there has been no generalized assessment of the total damage occurring. In addition, it is difficult to attach monetary figures to the damage except in cases such as the relocation of wells. How can one attach a value to mature sugar maples lining the edge of a highway?

The accelerated corrosion of vehicles which results from contact with salt has been confirmed (54,55,56). Salt itself is not corrosive; rather the salt on the surface of the metal causes the retention of moisture, raising the rate of corrosion to an abnormally high level. A study by the American Public Works Association (56) has shown that "up to 50 per cent of vehicle corrosion can be attributed to the action of deicing salt". Estimates of the cost per vehicle per year range as high as \$200. The Society of Automotive Engineers has placed the figure at approximately \$100 per vehicle each year (46, 50). Even if the actual amount were as low as \$50, this would imply a cost of \$3 billion per year for the residents of the snow belt states (based on 60 million vehicles). Therefore, it would be worth spending as much as \$3 billion per year to avoid the salt damage to vehicles.

Damage to pavement and highway structures has also been confirmed (51). Bridges are especially vulnerable because they are supported by steel structures which are easily damaged by salt solutions. Reinforcing rods within the concrete pavement cannot be easily protected and their corrosion causes the structure to weaken and the pavement to crack. Unfortunately, cost estimates of the chemical damage have not been made. One source (51) claims that without salt, concrete bridge decks could be expected to last 25-30 years before reinforcing was required, but with salt the decks would last only about 20 years. Based on these estimates, the maintenance costs of bridge decks is increased by 25-50 per cent due to chemical damage. However, this figure must be substantiated by further research before drawing conclusions about the cost of bridge deck damage. This is also the case with highway surfaces. While it is generally accepted that deicing chemicals cause scaling and cracking of pavement, further research must be done to determine the exact effects of salt.

Commonly Used Deicing Chemicals

The purchase and application costs of salt are fairly well known. Including delivery to a salt storage and pick-up area, the purchase cost of sodium chloride ranges from \$10 to \$20 per ton. (56) Calcium chloride costs between \$30 and \$35 per ton. Dispensing costs have been estimated at \$.10 per lane mile for the vehicle. Labor costs, based on \$4 per hour wage and vehicle speed of 20 mph are approximately \$.20 per two-lane mile (since spreaders normally cover two lanes), or \$.10 per lane mile. It should be noted that in many cases there might be two crew members per truck and that the work might be done on overtime, raising the labor cost substantially. Recommended salt application rates for sodium chloride range from 150 to 400 pounds per lane mile (35,36). Using these figures, total cost after application could be as low as \$1.00 or as high as \$4.40 per lane mile. According to other sources, the total cost for applied salt is \$18 to \$25 per ton (58, 59). This would imply a per lane mile price of approximately \$1.40 to \$5.00 depending on the application rate. For calcium chloride the price

ranges from \$2.45 to \$7.40 per lane mile

Salt use in Maine is approximately 400 lbs. per lane mile with an average of 125 applications per season (35), or a total of 25 tons of salt per lane mile. This implies a cost close to \$500 per lane mile per season. This amount is not unusual - during the winter of 1966-67, the District of Columbia, Massachusetts, Pennsylvania, and Illinois are known to have applied 20 to 37 tons of salt per lane mile. Since that time, nationwide use of salt has grown more than 50 per cent to a present level of approximately 10 million tons a year at a total cost of \$200 million.

The general lack of knowledge of the damage caused by salt and the inability to assign costs to much of the damage make it extremely difficult to make precise cost evaluations. Therefore, we will use only the costs for salt application and vehicle corrosion as firm figures in our comparisons. Environmental and pavement damage costs will have to be left out of the analysis while remembering that there are very real, and probably significant, costs involved.

Alternate Chemicals - An Example

While the findings of this project do not condone the use of chemicals because of the lack of knowledge of their effects, we present an example cost comparison for urea in order to demonstrate the importance of considering all costs.

The purchase price of urea is approximately \$90 per ton or six times that of salt. To obtain the same deicing results, 1 - 1/2 to 2 times the amount of salt required must be used. To replace the 10 million tons of salt we must use 15 to 20 million tons of urea costing \$1.35 to \$1.8 billion (whereas the salt cost \$150 million). Urea is much less corrosive to vehicles than salt so let us assume that auto damage amounts to only \$1.5 billion (probably a high estimate) instead of

\$3 billion for salt. Together with a spreading cost of \$75 to \$100 million (1 1/2 to 2 times that of salt), urea costs between \$2.9 and \$3.35 billion as compared to \$3.2 billion for salt. This demonstrates the fallacy in the argument that urea would be 9 to 12 times the cost of salt.

UCAR Runway Deicer made by Union Carbide for airport use also compares favorably to salt. Its primary ingredient is ethylene glycol. The chemical causes essentially no corrosion in vehicles and is totally biodegradable (although this does not necessarily make it safe for the environment). Its cost is \$180 per ton, and approximately 1 1/2 to 2 times the amount of salt is needed for equal melting. Spreading costs would be about \$75-\$100 million. Damage to automobiles, pavements and bridges would be near zero. Consequently, annual costs would range from \$2.8 to \$3.7 billion, still a reasonable cost without even considering the saving on pavement damage. It should be noted that the \$180 per ton price might be lowered if the product were mass produced.

Chelating Agent

While we do not have a specific chemical to recommend, we will demonstrate what cost could be justified for its use. Let us assume that the chelate would reduce the corrosion effect of salt on vehicles by 50 to 75 per cent (some corrosion will occur since free salt will be picked up by the vehicles until the chelate is applied). Consequently, corrosion costs would be \$.75 to \$1.5 billion. Subtracting \$100 million for application leaves \$1.4 to \$2.15 billion in savings, which is the maximum amount we could afford to spend on the chelate to effect a net savings. Dividing this amount by 20 million tons gives a cost of \$70 to \$107 per ton. If an adequate chelate could be found which costs less than this amount, its use would be beneficial. If the cost of pavement and environmental damage were known and included in this evaluation, then the allowable cost for the chelate would be significantly higher. By not including these costs, we have arrived at a conservatively low allowable price for the chelate.

Mechanical Devices

The compressed air system and the brush and blower can be considered similar in their functions. They are able to remove almost all types of snow but usually very little ice. Their use alone would definitely reduce, but not eliminate, the need for chemicals. Snow could be removed more easily and completely without need for salt. In addition, more complete removal would mean less moisture on the road to form an ice slick at a later time. Total snow and ice clearing costs per season (plowing, sanding and salting) in the northeast are estimated to be \$1,000 per lane mile, about half of which is for salt. If we were able to double the number of trucks (with compressors, etc., added) and raise the effective plowing costs by 20 per cent to account for the increased equipment purchase price, the "plowing" costs would be about \$1,200 per lane mile. At the same time, we could probably cut the salt use by 50 per cent, reducing the salt cost to \$250 per lane mile. The net increase is \$450 per lane mile, about 90 per cent of the original cost of salt per lane mile. Using the total salt cost of \$150 million, this would imply an increased clearing cost of approximately \$135 million. However, with the salt use cut by 50 per cent we could expect vehicle corrosion to be reduced. If we assume that the corrosion damage also drops by 50 per cent, the savings will amount to \$1.4 billion. Even if the plowing were increased five-fold, the cost savings would still be \$.825 billion. This is still a substantial savings, demonstrating that the introduction of the new mechanical devices is probably well justified.

Pavement Heating

Pavement heating is a more complete solution to the snow and ice problem because it eliminates the need for all other procedures - plowing, sanding and salting. Pavements would be free of snow and ice at almost all times, further reducing the chance for accidents. Chemical pollution of the environment would be traded for another form of pollution resulting from the power requirements for road heating. While the cost for installing a heating system in a new road

or a paved area is high, addition to an already existing road or paved area is more than likely out of the question. Thus, the installation is mainly applicable to paved areas such as new roads, roads undergoing major resurfacing, short road spans, or parking and walkway areas which warrant the addition for safety reasons. The costs for prototype systems are shown in Table II. The operating costs are for average winter conditions in the northeast. It is expected that the installation costs could be reduced once efficient procedures were developed.

To compare the cost of a heating system to the present methods, let us consider a one mile lane which is 10 feet wide. The area is approximately 50,000 square feet with a resulting annual operating cost of \$16,000 to \$22,000 for an electric system; \$5,000 to \$7,500 for a fuel burning system, or about \$500 for a heat exchanger. Comparing this to the present total cost of \$1,000 per lane mile per season, only the heat exchanger would seem reasonable. However, this system would require a capital cost of at least \$300,000 per lane mile, making it also infeasible for large scale use. The reduction in vehicle corrosion must be considered. It is clear that the corrosion cost would be zero if pavement heating replaced salt on all roads. This is highly unlikely--only a few special locations might use heating systems with the result that vehicles would still be exposed to almost the same amount of salt. Highway damage might be reduced at the location of the heater if salt were not carried from other locations by vehicles.

Tests to date probably have not shown accurate maintenance costs, which could be high for the fluid circulating systems. Installation for the heat exchanger is probably much higher than the cost of the other systems, possibly making this system unattractive, despite its extremely low operating costs. It appears that the heating systems can be justified only in cases where ice and snow are difficult to remove, where extremely hazardous conditions exist, or where salt poses a serious threat to highway structures or the environment. Such cases must be evaluated individually--no general rule of thumb can be applied.

TABLE II

PAVEMENT HEATING SYSTEM COSTS PER SEASON

System Type	Installation Cost Costs (per sq.ft.)	Operating Cost (per sq.ft.)
Fluid Circulating		
Earth Heat Exchanging	Not Established	Less than \$.01
Fuel Burning	(Estimated \$6 - \$12) \$4.00	\$.10 - .15
Electric		
Cable or Mat	\$2.00 - \$4.00	\$.32 - .45
Electrically Conductive	\$1.00 - \$3.00	\$.32 - .45

(References: 17, 18, & 51)

Hydrophobic Pavements

Although a specific substance has not been identified yet, this analysis will show the cost constraints for its use. If the surface of our roads could be made to release the ice, we would eliminate the costs of salting, vehicle damage, highway damage, and environmental damage. Based on the first two of these alone, the savings would be approximately \$3.2 billion annually. Let us suppose that the substance would have to be applied once a year, ideally just before the snow season. Suppose also that there are approximately 1 million miles of road that would have to be treated - a liberal estimate considering it is about 27% of all the roads in the U.S. (60). Let us also suppose there is an average of three lanes per mile, each ten feet wide. Then the allowable cost per square foot including application costs for the substance is:

$$\frac{\$3.2 \times 10^9}{1 \times 10^6 \text{ mi.} \times 30 \text{ ft} \times 5280 \text{ ft/mi}} \sim \$0.02 \text{ sq. ft.}$$

If the substance were able to cover about 250 square feet per gallon, then the allowable cost would be \$5 per gallon including application costs. If the chemical could be applied by spraying from a moving truck (as liquid devices are now applied), the application cost would be fairly low leaving most of \$5 per gallon for the purchase of the substance.

It is extremely important to note that this \$5 breakeven figure is low because we have not included any costs for pavement, highway structure, and environmental damage in the \$3.2 billion figure. Inclusion of these costs could raise the breakeven price considerably.

A number of chemicals have been identified in Section V which would have the required hydrophobic properties. However all of these are likely to suffer from at least one main deficiency - short wearlife. Tests should be made to determine their expected life. The cost for some of these chemicals is as low as \$.60 per pound or about \$5.00 per gallon. With the mass production required to produce enough for large scale use, the price might drop considerably.

A summary of the evaluations in this section is displayed in Table III.

TABLE III
Summary of Cost Evaluation
(all costs per season)

METHOD OF SNOW AND ICE CONTROL	Chemical Cost (per lane mile)	Installation Cost (per lane mile)	Application Cost (per lane mile)	Operating Cost (per lane mile)	Maintenance Cost (per lane mile)	Residual Life (years)	Theoretically Allowed Cost (per con)	Cost of Method (Nationalwide)	Corrosion Costs to Vehicles (Nationalwide)	Total Cost (Nationalwide)
Salt (Present Method)	500	-	500	-	-	-	-	.2B	3.0B	3.2B
Urea	4.5-6.0K	-	750-1000	-	-	-	-	1.4-1.85B	1.5B	2.9-3.35B ^④
UCAR	9-12K	-	750-1000	-	-	-	-	2.8-3.7B	0	2.8-3.7B ^④
Chelate	5-7K ^①	-	1.5K	-	-	-	70-107	1.7-2.45B ^①	.75-1.5B	3.2B ^④
Mechanical (Reduced Salt)	200	-	200	1000	-	-	-	.3B	1.5B	1.8B ^④
Pavement Heaters:										
Heat Exchanger	-	320-600K	-	500	?	10-20	-	NA ^②	NA	NA
Fuel Burning	-	215K	-	5-7.5K	?	10-20	-	NA ^②	NA	NA
Electric Cable	-	102-215K	-	16-22K	?	10-20	-	NA ^②	NA	NA
Conductive Pavement	-	53-100K	-	16-22K	?	10-20	-	NA ^②	NA	NA
Hydrophobic Surface	1050	-	③	-	-	1	1000	3.2B ^①	0	3.2B ^⑤

K = Thousands of dollars
M = Millions of dollars
B = Billions of dollars

① Theoretically allowed

② Not intended for total replacement of salt

③ Included in chemical cost

④ Reduced pavement and environmental damage not indicated

⑤ Pavement and environmental damage reduced to zero

SECTION VII

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SECTION IX

APPENDICES

Page No.

A. Sample Computer Search Outputs

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B. List of Contacts

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APPENDIX A

SAMPLE COMPUTER SEARCH OUTPUTS

The following three pages are sample output from the computerized searches of Chemical Abstract Condensates, NASA, and the Bibliography on Cold Regions Science and Technology respectively. The first two of these have references only; the third includes an abstract. Since a search strategy must be sufficiently broad to ensure that all useful references are obtained, a majority of the documents identified by the search are necessarily irrelevant.

PROFILE: 910472 SNOW REMOVAL AND ICE CONTROL PERRY

DOCUMENT: 006009

- 0: CA VOL. 72. ABST. NO. 006009
- 1: HYDROPHOBIC COATING ON HYDRAULIC OBJECTS.
- 2: HUNG, BODIS, JANOS; PAPP, ENDRE; SIMON, AGOSTON; SZERECZ, JANOS;
- 3: BODIS, JANOS; PAPP, ENDRE; SIMON, AGOSTON; SZERECZ, JANOS; HUXAT156457 CL.
- 3: C 048) 22 SEP 1969, APPL. 27 MAY 1968; 8
- 4: HYDROPHOBIC COATINGS CONCRETES, COATINGS HYDROPHOBIC CONCRETES,

DOCUMENT: 006174

- 0: CA VOL. 72. ABST. NO. 006174
- 1: WATER- REPELLANT PERLITE FOR THE ABSORPTION OF OILY LIQUID
- 2: GER. OFFEN. CULEMEYER, KARL; DIEDRICH, ERWIN CULEMEYER K, DIEDRICH E.
- 3: GOLDSCHMIDT, TH. A. G. GWXXBX1807409 CL. 8 01G) 21 JUN 1989, SWISS APPL.
- 3: 14 DEC
- 4: REMOVAL OILS WATERS, GROUND WATERS OIL REMOVAL, OILS REMOVAL

DOCUMENT: 006205

- 0: CA VOL. 72. ABST. NO. 006205
- 1: ASSOCIATION COMPLEXES OF PROCAINE HYDROCHLORIDE WITH SODIUM LAURYL
- 2: CHEM. PHYS. APPL. SURFACE ACTIVE SUBST. PROC. INT. CONGR. 4TH VILA JATO J
- 2: L, OTERO AENLE E, CADORNIGA CARRO R.
- 3: FAC. PHARM. SAINT JACQUES COMPOSTELLE, SANTIAGO DE COMPOSTELA. 20UGAG VOL
- 3: 2, NO. 0, 1967, P. 735- 41.
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- 0: CA VOL. 72. ABST. NO. 015744
- 1: INTERACTION OF SODIUM ERYTHROSIN AND POLY(VINYLPYRROLIDONE)
- 2: J. PHARM. SCI. ANDERSON JC, BOYCE GM.
- 3: RES. LAB. ASTRA PHARM. PROD. INC. WORCESTER, MASS. JPMSAE VOL 58, NO. 11,
- 3: 1969, P. 1425- 7.
- 4: COMPLEX DRUGS ERYTHROSIN, POLYVINYLPYRROLIDINONE ERYTHROSIN

DOCUMENT: 024229

- 0: CA VOL. 72. ABST. NO. 024229
- 1: COMPLEX STUDY OF CONCRETE.
- 2: SOVERSH. METOD. ISSLED. ISEM, KAMNYA BETONA LARIONOVA ZH, NIKITINA LV,
- 2: GAKASHIN VR, VOLKOV OS.
- 3: USSR) 21ABA8 VOL 0, NO. 0, 1968, P. 43- 56.
- 4: ALUMINATES CA HYDRATED, PHASES HARDENED CEMENT, HYDRATED CA

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MAR. 1, 1960 - JAN. 31, 1961 LEE M. KINDLEY WRIG
HT-PATTERSON AFB, OHIO, AERONAUTICAL SYSTEMS DIV.,
APR. 1961 128P 16 REFS /CONTRACT AF 33/616/-701
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EVALUATION OF FINCH PAINT COMPANY'S PROPRIETARY
COATING SYSTEM /ADHESION TESTS/

A/DHR, J.

NAVAL AIR ENGINEERING CENTER, PHILADELPHIA, PA.
(AERONAUTICAL MATERIALS LAB.)

2 SEP. 1966 13 P REF

/ ADHESION/ ALUMINUM/ EPOXY/ IMMERSION/ PRIMER/
SURFACE/ TEST/ WATER

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IED DOCUMENT GOVT. AGCY. ONLY

ON THE ADHESION OF ICE TO VARIOUS MATERIALS

A/PRICE, R. D.; B/STALLABRASS, J. R.

NATIONAL RESEARCH COUNCIL OF CANADA, OTTAWA (ONT
ARIO). (DIV. OF MECHANICAL ENGINEERING.)

JUL. 1962 23 P REFS

/ ADHESION/ AIRCRAFT/ APPARATUS/ CENTRIFUGAL/ C
OATING/ DROP/ ICE/ IMPACT/ LOW/ MATERIAL/ PENETRAT
ION/ PORE/ STRUCTURAL/ TEFLON

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PARTICLE ADHESION IN THE PRESENCE OF A LIQUID FI
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A/CROSS, N. L.; B/PICKNETT, R. G.

CHEMICAL DEFENCE EXPERIMENTAL ESTABLISHMENT, POR
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/ ADHESION/ BALANCE/ FILM/ LAYER/ LIQUID/ PARTI
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001 26-2118

100 Hearst, P.J.

245 DEICING MATERIALS FOR MILITARY RUNWAYS

504 U.S. Naval Civil Engineering Laboratory, Port Hueneme,
Calif. Technical memoranda

250#b March 1957/M-124

035 AD-143 509

690 DEICERS

652 RUNWAYS

652 TESTS

652 EFFECTIVENESS

740 Deicing materials for melting ice on runways

520 Various noncorrosive chemicals were investigated to determine their suitability and effectiveness as materials for melting ice on runways. Properties studies included, the ability to lower the freezing point of water, the heat of solution, and the rate of melting ice. It was found that in order to have a reasonably high rate of melting ice, a deicing material must be heavier than water. Formamide containing 20 per cent urea and 5 per cent water as freezing point depressants is the best deicing material found for use at temperatures as low as -18 degrees centigrade (0 degrees Fahrenheit). This mixture is effective at still lower temperatures if a certain amount of slush formation can be tolerated and if it is applied at temperatures no lower than about -18 degrees centigrade. At much lower temperatures ammonium acetate may be a satisfactory deicing material.

501 b

502 h

008 15.eng 20.m 21.5703 23.us

APPENDIX B

LIST OF CONTACTS

The following persons and agencies were contacted in regard to the project:

L. David Minsk

U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, N.H.

Adrian G. Clary

Highway Research Board
Washington, D.C.

Charles Dougan

Bureau of Research and Development
Connecticut Department of Transportation

Dr. C.J. Posey

University of Connecticut

Bernard Chaiken

Chemistry and Coatings Group
Federal Highway Administration

Harry Smith

National Cooperative Highway Research Program
Highway Research Board

J. Allan Schofield

Union Carbide Corporation
Tarrytown, New York

William Latham
Kaiser Chemical Co.
Savannah, Georgia

Jack Slater
Kaiser Chemical Co.
Savannah, Georgia

William Tyler
NASA Scientific and Technical Information Facility
College Park, Maryland

Mark Helyer
New England Research Applications Center
Storrs, Connecticut

Edward Perry
New England Research Applications Center
Storrs, Connecticut

John Feulner,
National Referral Center
Library of Congress

Geza T. Thuronyi
Cold Regions Bibliography Project
Library of Congress

Professor Clark Colton
Chemical Engineering
Massachusetts Institute of Technology

Professor Lynn Gelhar
Hydrology,
Massachusetts Institute of Technology

Professor David Adler
Electrical Engineering
Massachusetts Institute of Technology

Professor David Wilson
Mechanical Engineering
Massachusetts Institute of Technology

Department of Public Works
Control and Research Laboratory
Montreal, Canada

Department of Transportation
State of Illinois

Department of Transportation
Division of Research and Development
Bureau of Instrumentation Services
Trenton, New Jersey

Department of Highways
State of Ohio

Division of Building Research
National Research Council
Ottawa, Canada

Road Research Laboratory
Ministry of Transport
Crowthorne, Berkshire
England

Ministère de la Voirie
Gouvernement du Québec
Québec, Canada

Professor Frederick Moavenzadeh
Mechanical Engineering
Massachusetts Institute of Technology

Dr. Anthony E. Lintner
Chemical Engineer Consultant
Pittsburgh, Pennsylvania

William Burling
Department of Public Works
Burlington, Massachusetts

Professor Robert C. McMaster
Department of Welding Engineering
Columbus, Ohio